DEPENDENCE OF THE LIGHT SCATTERING PHASE MATRIX OF CRYSTAL CLOUDS ON ORIENTATION AND CHARACTERISTIC SIZE OF PARTICLES

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The results are presented of light scattering phase matrix simulation depending on characteristic size of polydisperse ensemble of elongated particles and their orientation. Appearance of a preferred particle orientation in a plane orthogonal to the direction of the incident radiation is shown to cause a sharp increase (approximately, 10^2) of the backscatter.

The presence of crystal aerosol structures in the upper–level clouds causes the anisotropy of their optical properties. In this connection, some optical effects of light scattering by cirrus clouds can not be interpreted within the framework of the Mie theory models. Analysis of the problem out of the hypothesis on spherically symmetric shape of aerosol particles leads to a serious extension of the list of the initial parameters. The problem arises of summarizing the numerical estimates obtained in different coordinate systems into the united one connected with the scattering plane. Analysis was performed in Refs. 1–4 of the light scattering properties of the upper–level clouds on the base of finite cylinder approximation obtained for far diffraction zone as assessed from exact solution for infinite cylinder in the near zone, taking into account nonsphericity. Comparison of our estimates with analogous results obtained for elongated spheroids confirmed usefulness of our approach to analysis of the light–scattering properties of crystal structures.[3]

Some features were considered in Ref. 4 of the formation of light scattering phase matrix (LSPM) of cirrus clouds when changing the orientation of particles relative to the direction of incident radiation at a relatively small particle size. In this paper we present the results of model estimates that are the continuation of previous studies[4] and illustrate the influence of particle orientation in the case of large particles.

CALCULATION RESULTS

The LSPM element values were calculated according to the procedure described in Ref. 4, i.e. averaging over the particle size and orientation was carried out using the Monte Carlo method. Convergence of the integral was estimated numerically. Distribution over the cross section radius was modelled as a lognormal one with the mean geometric radii r_m = 1, 10, 30 μm and standard deviation σ = 0.5. The ratio of a cylinder length to its cross section radius was assumed to be uniformly distributed in the range 8–10.

Two variants of particles orientation were considered: the cylinders with uniform distribution of axes in the plane orthogonal to the incident radiation and with chaotic distribution in three–dimensional space. All calculations were carried out for incident radiation at λ = 1.06 μm and refractive index $m = 1.299 + i\cdot 10^{-6}$, i.e. for ice needles. Thus, considered in calculations were the crystals with the maximum size of the order of ~600 μm.

Shown in Fig. 1 are angular dependences of the reduced LSPM elements for the ensemble of circular cylinders with finite length (CCFL) uniformly oriented in the plane orthogonal to the incident beam for different cross section values. Analogous data are shown in Fig. 2 for crystals randomly oriented in the three–dimensional space.

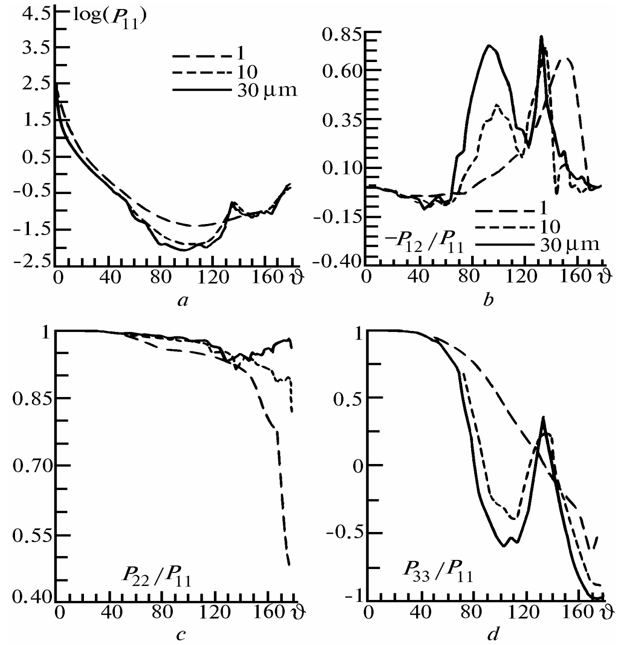

FIG. 1. Angular dependences of reduced values of the light scattering phase matrix elements for ensembles of circular cylinders uniformly oriented in horizontal plane with different mean geometric radii.

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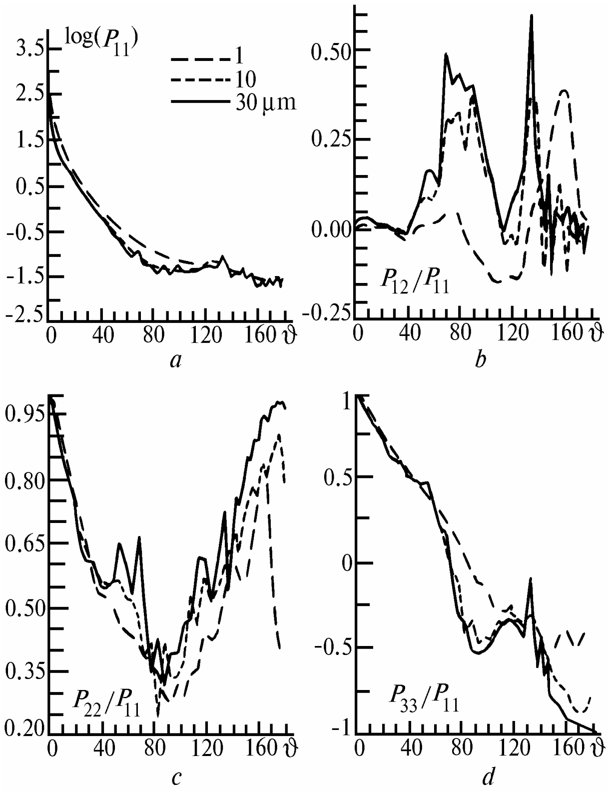

FIG. 2. The same as in Fig. 1 but for cylinders uniformly oriented in space.

Appearance of preferred orientation plane (in this case, the plane orthogonal to the incident radiation) results in a sharp increase of the backscatter, by about 10^2. It is clearly seen from the comparison of Figs. 1*a* and 2*a*.

The fraction of radiation scattered in lateral directions and into the front hemisphere essentially increases for random orientation of particles (Fig. 2*a*).

The pronounced maximum is observed for large particles in the rainbow region of $\theta \sim 130–140°$ in the case of preferred orientation plane. Specific behavior of light scattering is especially pronounced in the rainbow region on the curve of the polarization degree, Figs. 1*b* and 2*b*. In addition, the complex maximum that is absent for the particles with modal radius ~1 μm appears in both cases for large particles in the polarization curve in the angular range 75–125°. In general, the polarization curve has a more complex structure in the second case than in the presence of preferred orientation.

Angular dependence of reduced values of the scattering phase matrix element $P_{22}(\theta)$ in the presence of preferred orientation plane differs a little bit from analogous data for spheres in the scattering angle range 0–120°. Nonsphericity in this case is noticeable only near lidar angles and especially at the angle $\theta = 180°$. Quite opposite situation we have with the randomly oriented cylinder axes. In this case the behavior of $P_{22}(\theta)$ essentially differs from spheres along practically all directions and has quite a complex oscillating structure.

Thus, based on the results of these calculations and the data presented in Ref. 4 one can conclude that preferred orientation of cylinder particles relative to the incident beam is an important piece of formation of the light scattering properties of nonspherical aerosol particles and significantly affects the polarization of scattered light. The appearance of the plane of preferred orientation (type *1*) essentially changes the light scattering properties in comparison with the ensembles of particles with random volume orientation (type *2*). In particular, ensembles of the second type have significantly stronger depolarizing properties in the case of polarized incident radiation than ensembles of the first type. In their turn the ensembles of the first type has significantly stronger polarizing properties in the case of unpolarized incident radiation than those of the second type. The intensity of light backscattered by ensembles of the first type is two orders of magnitude greater than that for ensembles of the second type.

Depolarization of the backscattered light practically does not depend on orientation of cylindric particle axes relative to the incident radiation direction and is determined by a cylinder size and orientation relative to the reference plane.

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